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# STRESS DETERMINATIONS AT STANLEIGH MINE, ELLIOT LAKE, ONTARIO

B. ARJANG

ELLIOT LAKE LABORATORY

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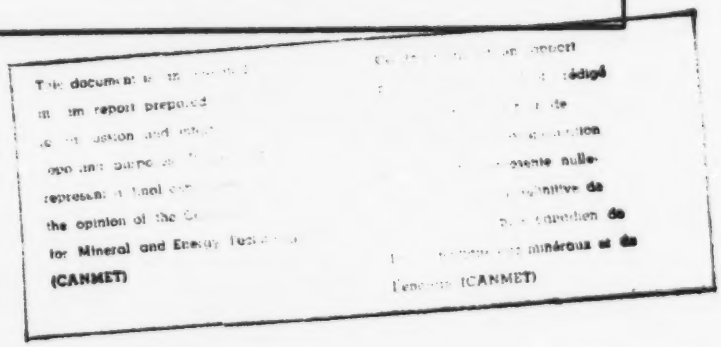

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# STRESS DETERMINATIONS AT STANLEIGH MINE, ELLIOT LAKE, ONTARIO

by

B. Arjang*

## ABSTRACT

Stress determinations were performed at the Stanleigh Mine of Rio Algom Ltd., in Elliot Lake. Elastic strain recovery measurements were carried out at a depth of 1066 m, with an overcoring technique using CSIRO triaxial strain cells. Based on stress determinations the pre-mining vertical stress, as well as the horizontal stresses parallel and perpendicular to the uraniferous conglomerate reef were established:

$\sigma$ vertical = 0.0263 $MN/m^3$ x depth (m) in MPa

$\sigma$ horizontal parallel to strike = 2.0 x vertical

$\sigma$ horizontal perpendicular to strike = 1.4 x vertical

Results indicated that the maximum pre-mining stress field lies in a sub-horizontal plane. An average horizontal stress of about 1.7 times the vertical stress exists. The measured pre-mining stresses were comparable with the typical data obtained in the Elliot Lake region.

Evidence of core discing and spalling in vertical exploration drill holes confirmed the existing high east-west stresses.

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* Research Scientist, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario.

# MESURE DES CONTRAINTES À LA MINE STANLEIGH, ELLIOT LAKE (ONTARIO)

par

B. Arjang*

## RÉSUMÉ

On a procédé à la détermination des contraintes à la mine Stanleigh de la Rio Algom Ltd., à Elliot Lake. Des mesures visant l'appréciation du taux de déformation élastique des roches ont été prises à une profondeur de 1066 m à l'aide d'une technique poussée de carottage en utilisant des cellules de déformation triaxiale CSIRO. En se fondant sur les mesures de contraintes, la contrainte verticale la plus appropriée ainsi que les contraintes horizontales parallèles et perpendiculaires au récif uranifère conglomeré présentes avant les travaux d'extraction minière ont été établies:

$$\sigma \text{ vertical} = 0{,}0263 \text{ MN/m}^3 \times \text{profondeur (m) en MPa}$$

$$\sigma \text{ horizontal parallèle au filon} = 2{,}0 \times \text{vertical}$$

$$\sigma \text{ horizontal perpendiculaire au filon} = 1{,}4 \times \text{vertical}$$

Les résultats indiquent que le champ de contraintes maximal avant les travaux d'extraction se situe sur un plan sous-horizontal. Une contrainte horizontale moyenne d'environ 1,7 fois la contrainte horizontale existe. Les données sur les contraintes existant avant les travaux d'extraction sont comparables aux données typiques obtenues au cours d'études dans la région d'Elliot Lake.

Des signes évidents, tels l'écaillage et la fragmentation des noyaux de roche se trouvant dans les trous de forage verticaux ont confirmé l'existence de fortes contraintes est-ouest.

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*Chercheur scientifique, Laboratoire d'Elliot Lake, CANMET, Énergie, Mines et Ressources Canada, Elliot Lake, Ontario.

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## INTRODUCTION

In the Elliot Lake area ground stress measurements have been conducted in the Denison Mine and the Nordic Mine, between 305 to 939 m depth (1-5). Stress measurements had not been undertaken at Stanleigh Mine, the deepest mine in the area. The data obtained at higher levels in adjacent mines and/or the estimated pre-mining stress values had been used for mine design purposes. Extrapolation of the data down to a depth of about 1250 m at Stanleigh Mine needed to be confirmed.

Stress measurements at Stanleigh Mine were done in the vicinity of a major dyke. Through-cutting dykes, exhibited to a significant extent in the mine workings, seem to have an effect on stress distribution.

Measurements were planned on both sides of the major dyke and within the dyke itself, but could only be completed in the hanging wall of the dyke because of technical difficulties and time limitations.

## GEOLOGICAL SETTING

Stanleigh Mine is situated on the southern limb of the broad Quirke Lake syncline. A sequence of thick layered quartzite and massive quartz-pebble conglomerate reefs strike nearly east-west, dipping towards north at about 10°. The uraniferous conglomerate of the lower reef, main reef and upper reef are 1050 to 1250 m below surface.

Dominant structural features are easterly-oriented steeply dipping joints, dykes and strike faults. These act diagonally to the bedding plane, or conglomerate reefs. In a relative comparison the quartzite rocks are more frequently fractured than the conglomerate. Fractures rarely penetrate into the conglomerate (6). The quartzite beds are up to 4 m thick with sub-rounded grains, closely packed and cemented.

A detailed study of fabric elements showed that the compression axis for the main deformation within the Quirke Lake syncline is oriented in a northerly direction (7). Relaxation of this compression possibly accounts for some of the NW and EW oriented, steeply dipping faults which were subsequently intruded by basic dykes (8,9).

## FIELD MEASUREMENTS AND LABORATORY TESTS

Stress determinations were carried out on the 1066 m level (3512 haulage drift east). The test site was selected away from the on-going mining activity to minimize the effects of mining-induced stress concentration.

Stresses were determined with an overcoring technique, using the Australian CSIRO hollow inclusion triaxial strain cells. Details of the procedure and information on the technical specifications of instruments and the strain cell are given in the literature (10). In principle, the oriented strain cell is grouted into the EX-size hole which has been centrally drilled in the end of a 153 mm diameter hole. As the rock core deforms to its unstressed shape during overcoring, the strain gauges distort and their response is monitored via the read-out cable attached to the cell.

Two holes were drilled at inclinations of 6° and 13.5° above horizontal. The test holes were drilled in the quartzite rock, from the mine opening which was 3.7 m square. The test locations and the directions of the drill holes are shown in Fig. 1. Figure 2 shows a schematic section of the mine at the test location.

A total of five overcoring tests were performed, of which two were successful (ST1-4 test in No. 1 hole, ST2-1 test in No. 2 hole). In the first three tests (ST1-1, ST1-2 and ST1-3) attempted in No. 1 hole, core breakage occurring either from the discing or fracturing during overcoring made it impossible to obtain elastic strain recovery measurements.

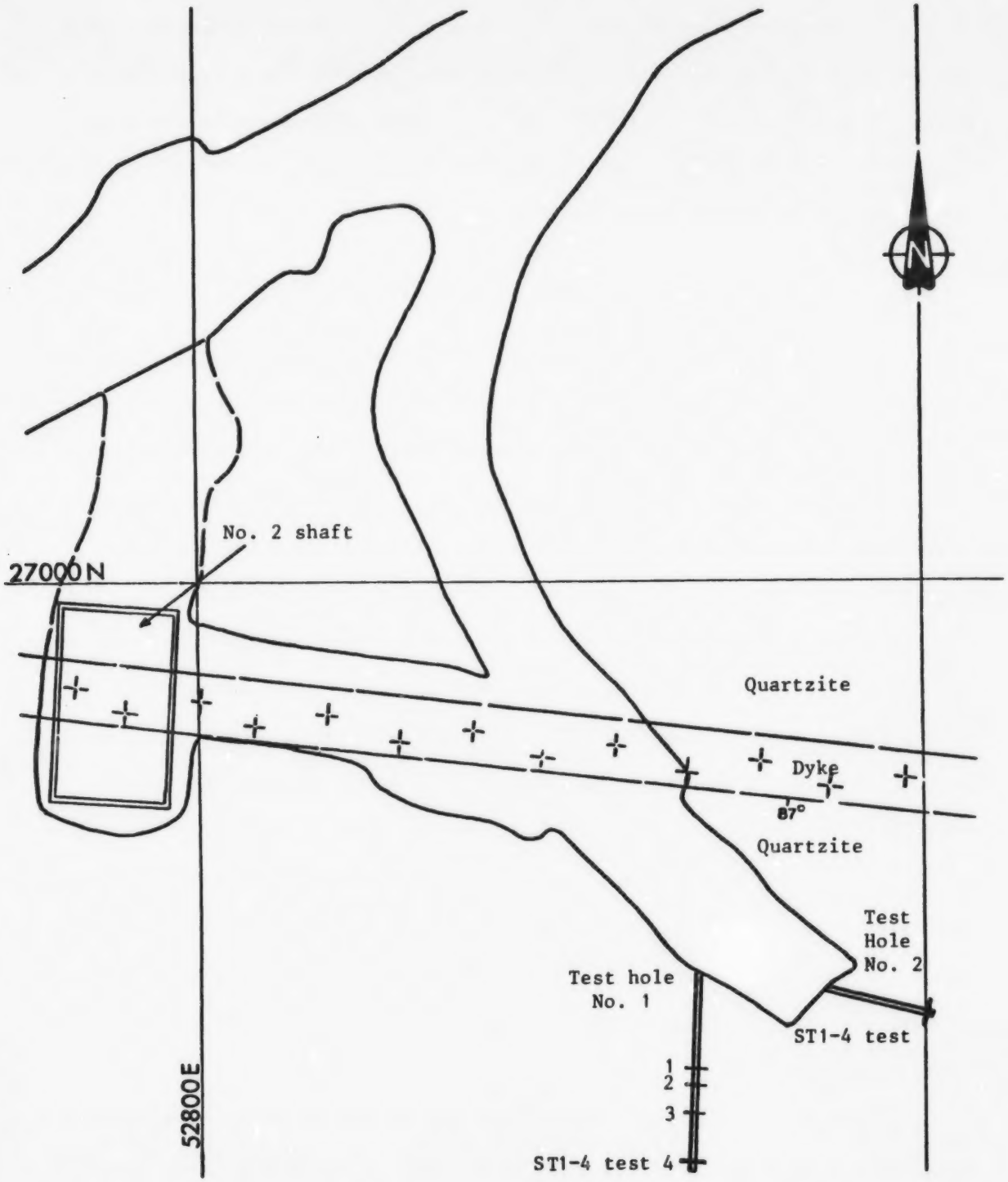


Fig. 1 - Stress determination sites and test hole locations on the 1066 m level, Stanleigh Mine (Scale 1:240).

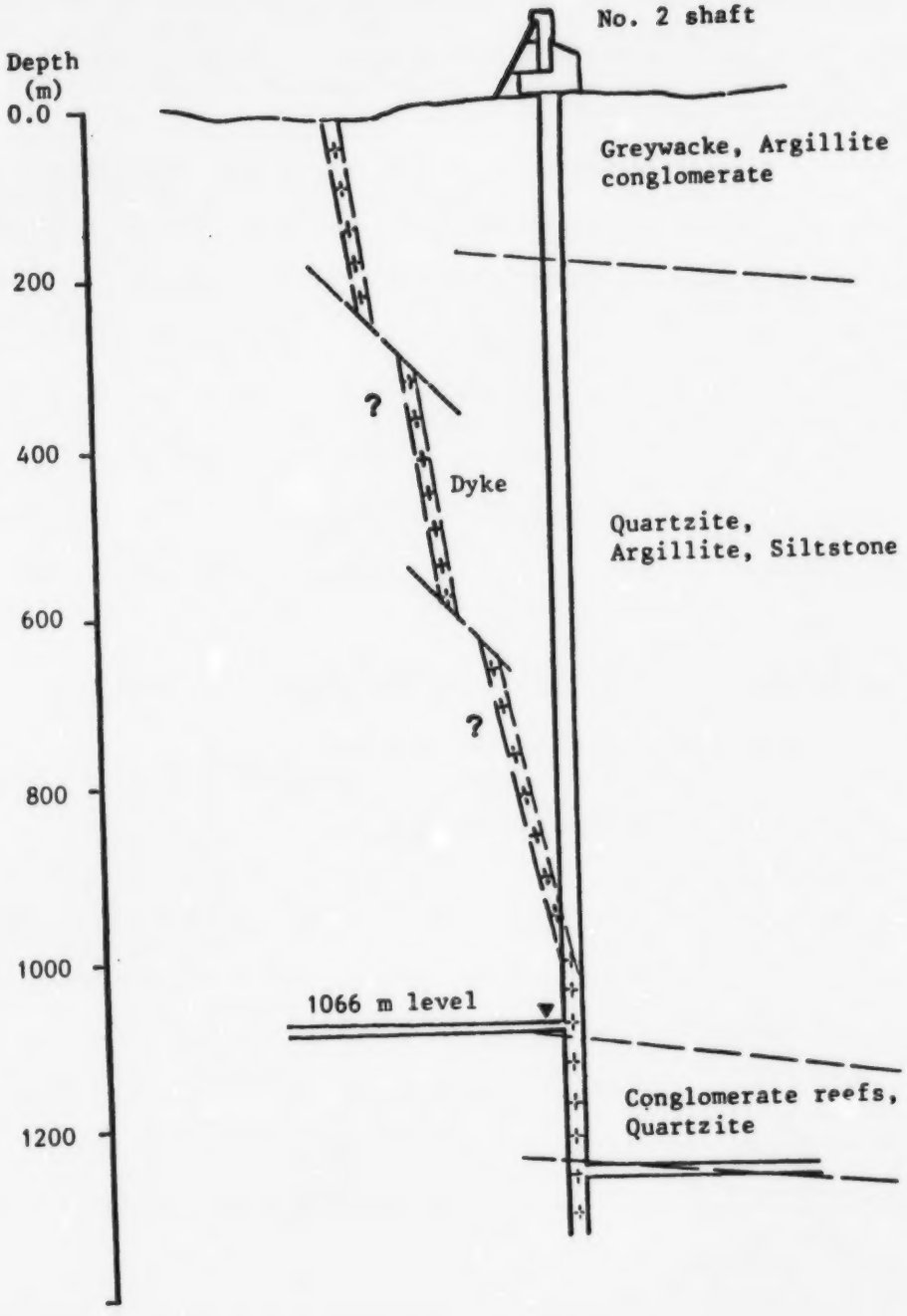


Fig. 2 - Schematic section of No. 2 shaft, Stanleigh Mine, (▼) test location.

Bonding of strain cells to the surface of the pilot holes was checked during quality testing in the laboratory. The axial sectioning of the overcores indicated well bonded strain cells, although the epoxy in the ST1-4 test contained some minor air bubbles.

Elastic constants were obtained in the laboratory. Representative solid core samples (diameter $\simeq$ 144 mm) were prepared with a length to diameter ratio of 2.5 and their ends ground to a parallelism of ±0.045 mm. Each sample was fitted with two pairs of strain gauges at mid-height in the vertical and longitudinal directions. Samples were loaded in the axial direction up to 270 MPa, or loaded to failure. The mean values obtained were an elastic modulus of 75.51 GPa, and a Poisson's ratio of 0.17, which were used for the stress tensor calculations. The mean uniaxial compressive strength on the core samples amounted to 262 MPa.

The rock properties tests indicated homogenous rock, with the differences in elastic constants being insignificant.

## STRESS CALCULATIONS

The composite elastic constants, the test hole bearing and dip in the mine grid system, and the strain recoveries during overcoring were taken as input data for the stress calculations. The data were processed by a computer program calculating the magnitudes and orientations of the principal stresses along with resolved vertical and horizontal stresses and relevant statistical information (11). The calculation results in the tensor of best fit according to a least square solution.

The elastic strain recoveries, the bearings and dips of the test holes, the setting depth of the strain cells, and the elastic constants, are given in Table 1. Table 2 provided the calculated stress components, and the magnitudes

Table 1 - Elastic strain recovery data from triaxial strain cell measurements on the 1066 m level, Stanleigh Mine.

| Test No. | Test Hole Bearing/dip (X) | Setting Depth from Collar (m) | Elastic Strain Recovery (με) | | | | | | | | | Elastic Modulus (GPa) | Poisson's Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | |
| ST1-4 | 182/-13.5 | 8.36 | 255 | 738 | 321 | 560 | 418 | 767 | 267 | 921 | 695 | 75.51 | 0.17 |
| ST2-1 | 103/-6 | 4.45 | 550 | 274 | 277 | 1317 | 555 | 1553 | 557 | 743 | 372 | 75.51 | 0.17 |

(X) Bearing in degrees clockwise from Grid North positive, dip in degrees (dip from horizontal positive down).

Table 2 - Stress components, magnitudes and orientations of the principal stresses from triaxial strain cell measurements on the 1066 m level, Stanleigh Mine.

| Test No. | Stress Components (MPa) (Standard errors in brackets) | | | | | | Principal Stresses Magnitude (MPa) and Bearing/Dip* | | |
|---|---|---|---|---|---|---|---|---|---|
| | Horizontal | | Vertical | Shear Stress | | | Major | Interm. | Minor |
| | $\sigma$ E-W | $\sigma$ N-S | $\sigma$ | $\tau$ N-S/E-W | $\tau$ E-W/V | $\tau$ V/N-S | $\sigma_1$ | $\sigma_2$ | $\sigma_3$ |
| ST1-4 | 28.55 | 31.91 | 28.19 | -0.44 | -2.14 | -3.57 | 34.18 | 29.61 | 24.86 |
| | (0.06) | (0.16) | (0.09 | (0.06) | (0.04) | (0.11) | 190/33 | 294/20 | 050/50 |
| ST2-1 | 57.48 | 39.65 | 21.48 | 9.17 | -6.93 | -4.51 | 62.96 | 35.88 | 19.76 |
| | (0.33) | (0.16) | (0.14) | (0.16) | (0.17 | (0.07) | 247/11 | 156/05 | 042/78 |

* Bearing in degrees positive clockwise from Grid North (Grid North is 6.5° west of True North); dip is the angle in degrees positive down from horizontal.

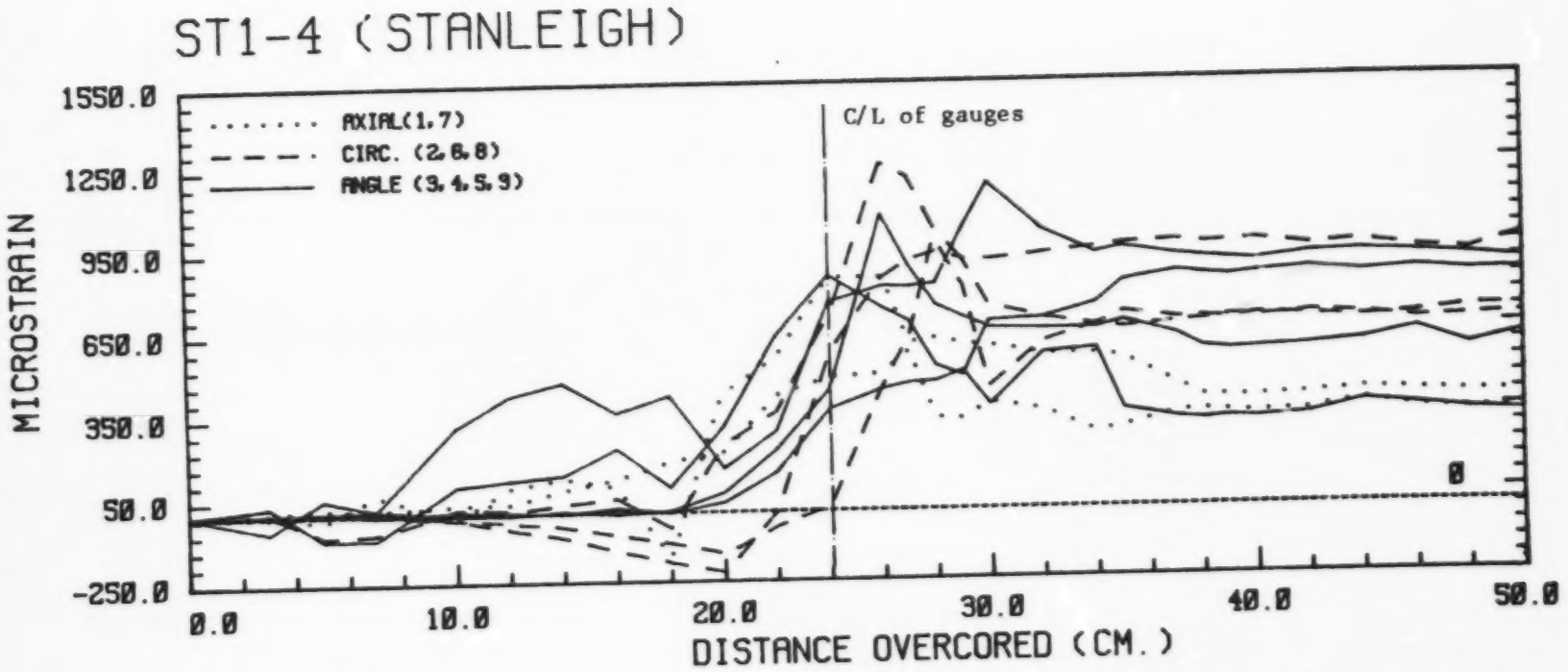


Fig. 3 - Overcoring response of gauges in ST1-4 test, on the 1066 m level, Stanleigh Mine.

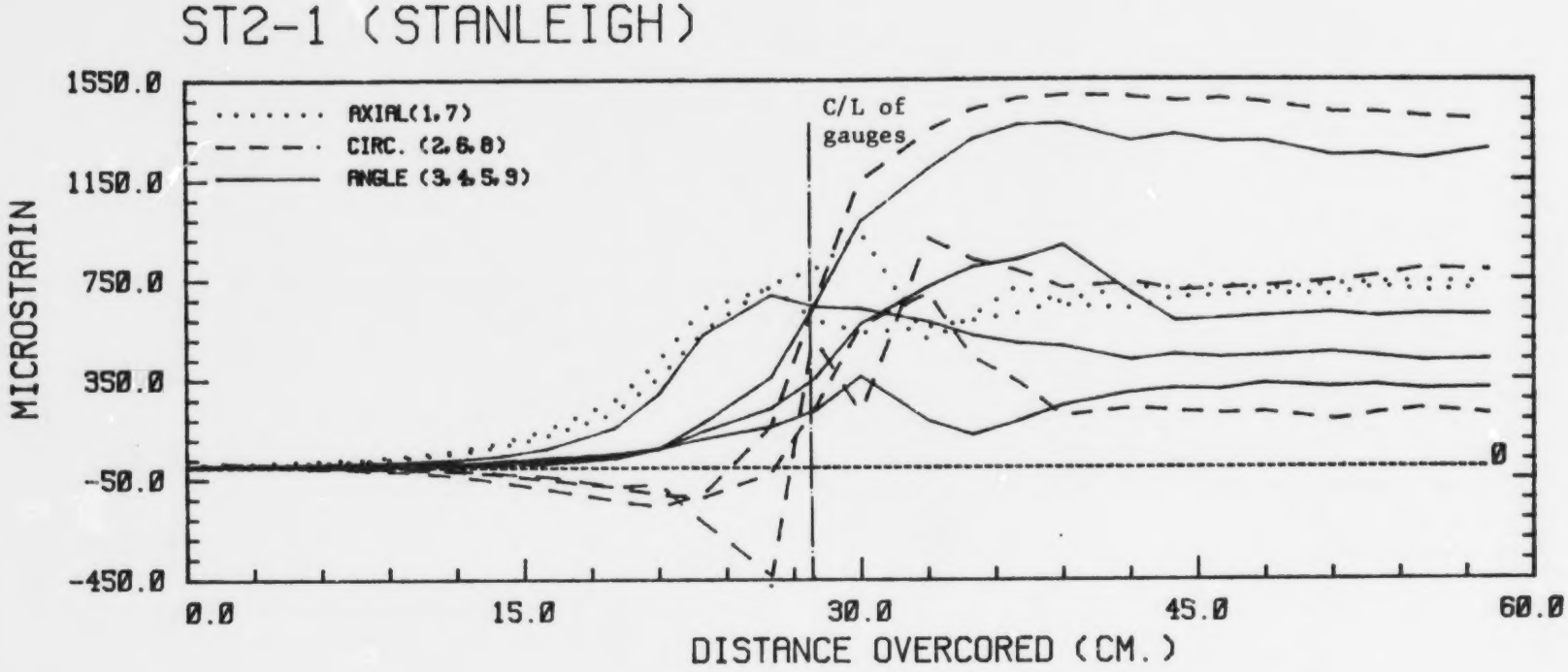


Fig. 4 - Overcoring response of gauges in ST2-1 test, on the 1066 m level, Stanleigh Mine.

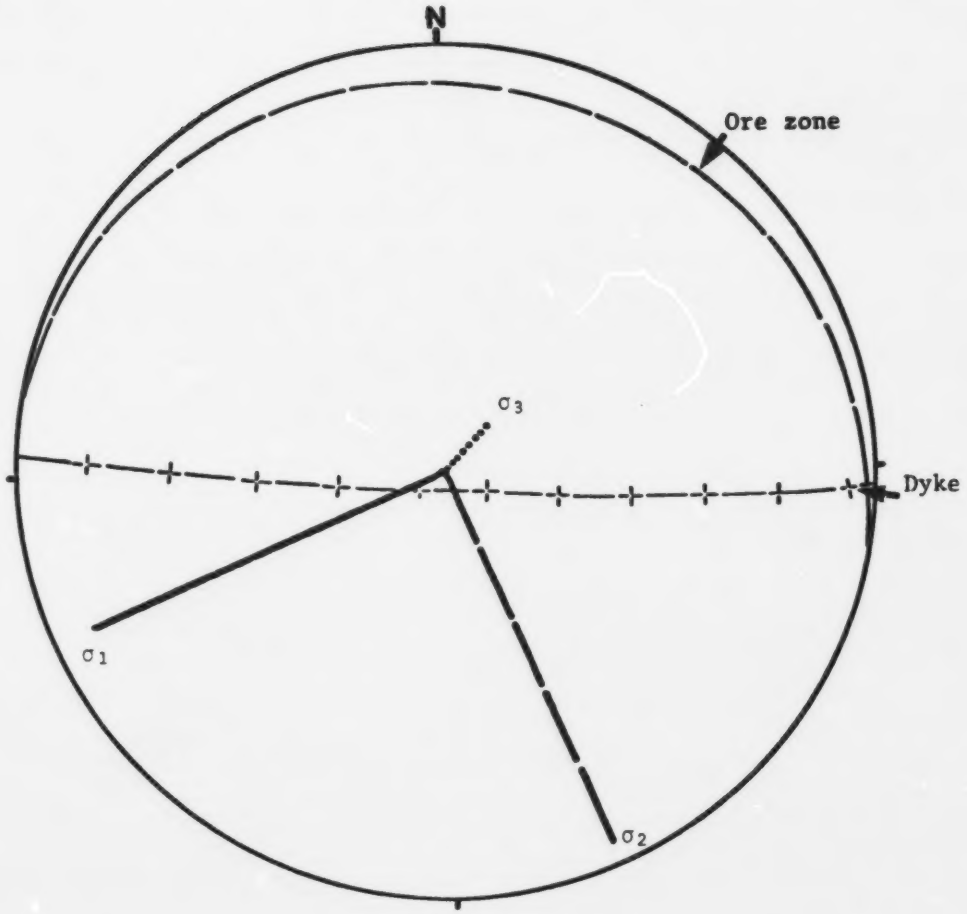


Fig. 5 - Principal stress direction (bearing/dip) from grid north on the 1066 m level in an equal area net, lower hemisphere projection; orientation of the ore zone and dyke are shown on great circles.

and orientations of principal stresses with respect to the mine grid system. The plots of gauge responses and the changes in microstrain are shown in Fig. 3 and 4. The orientations of the principal stresses, major dyke, and the ore zone are illustrated in Fig. 5.

## GROUND STRESS OBSERVATIONS

At Stanleigh Mine the first indication of high ground stresses was experienced during the shaft sinking (12). Squeezing ground and occasional small rock bursts occurred in No. 1 shaft from a depth of 760 m down, and in No. 2 shaft from a depth of 914 m down. A steeply dipping dyke of about 3 m thickness was encountered in the No. 2 shaft at 975 m depth and continued to the bottom. Ground failure was concentrated on the hanging wall rocks of the dyke, at the south wall of the shaft.

It is reported that during the late 1950's, roof and pillar failures were observed in the mine workings, as well as shearing at the pillar/roof corners and buckling of the roof (13). Recent inspections of old mine workings, after the shutdown period from 1962 to 1981, indicated that some pillars had failed violently (i.e., rockburst) (14). In the new mine workings some minor seismic activity has been recorded.

At Stanleigh Mine the existence of high ground stresses, in particular the high horizontal stresses, is supported by the occurrence of core discing in the stress measuring hole No. 1. The core breakage and discing was concentrated at a zone between 3.0 to 7.60 m from the mine opening. The thickness of core discs ranged from 20 to 50 mm. It should be noted that during the drilling process none of the EX-size cores (diameter $\simeq$ 24 mm) disced, while larger diameter cores ($\simeq$ 144 mm) broke into discs.

Generally, discing in cores occurs when drilling highly stressed rock.

According to experimental results (15,16), higher compressive stress and the tensile stress acting normal to the axis of the core by initiation of shearing are responsible for discing. Regarding the state of stress at the point of discing, this occurs if the horizontal compressive stress is greater than the vertical compressive stress, and related to the rock strength the radial in situ stresses are in excess of half of the compressive rock strength. These conditions suggest that the radial stresses applied to produce discing might have reached approximately 130 MPa at the test location (uniaxial compressive strength of quartzite obtained during laboratory tests amount to 262 MPa).

Some vertical exploration holes showed discing of cores (diameter $\simeq$ 24 mm) on the 1188 m level in the northern section of the mine workings. These were observed at a distance of about 2 to 10 m from the mine openings. The drill holes and the adjacent roof bolt holes indicated flaking along the N-S axis. The occurrence of discing and flaking confirms high horizontal E-W stress in the on-going mining developments.

In the experimental discing tests, a linear relationship between the axial ($S_a$) and radial ($S_r$) load required to produce discing was determined (15,18). Using the following equations, by substituting horizontal stress Sh for $S_r$, and vertical stress $S_v$ for $S_a$, the state of horizontal stresses in rock can be approximated:

$$K_1 = 3400 - 2.0\ S_o = 3400 - 2.0 \times 7000 = 10600 \text{ psi}$$

$$S_h = K_1 + K_2\ S_v = 10600 + 0.7 \times 4600 = 13820 \text{ psi}$$

$$\text{Horizontal stress, } S_h = 13820 \text{ psi (95.0 MPa)}$$

where, $K_1$ and $K_2$ are the constants for various rock types from the discing tests, $K_2$ = 0.7, the average slope of the radial versus axial stress curve for discing; shear strength $S_o$ = 7000 psi for Elliot Lake quartzite without axial load (19); vertical stress $S_v$ = 4600 psi is the estimated overburden vertical

stress at 1188 m working level, where the disced cores in vertical exploratory holes were obtained.

## DISCUSSION

Occurrence of core discing in No. 1 test hole, drilled normal to the maximum stress direction, indicates very high E-W stresses, but the measurements from ST1-4 test in this hole gave N-S as the major principal stress. Results were anomalous and not comparable with the representative data obtained in this region, but similar to those from 939 m level at Denison Mine. Because of highly stressed ground the possibility exists that the full strain recovery was not measured in this test, and accordingly lower values were obtained. The test results were excluded from the final evaluation.

Measurements from ST2-1 test in No. 1 hole, drilled in the direction of maximum stress, are in agreement with overall stress measurements and visual observations of core discing and borehole spalling.

Figure 6 shows the increase of vertical stress, average horizontal stress and variation of stress ratio, $\sigma H_a/\sigma_v$, as a function of depth obtained in the Canadian Shield (17). For comparison, the average horizontal stress of 48.5 MPa and the calculated vertical stress of 28.0 MPa with a stress ratio, $\sigma H_a/\sigma_v$, of 1.7 are plotted in this Figure. The plots show that the values obtained at Stanleigh Mine fit the range of typical data found in the Elliot Lake region and elsewhere in the Canadian Shield.

At Stanleigh Mine strain recoveries were measured at a distance of 10 to 15 m away from the major weakness plane (dyke). The influence of the dyke on the measurements is thought to be insignificant.

With regard to the structural evidence, a non-homogeneous field stress condition exists in the southern limb of the Quirke Lake syncline (1). Therefore,

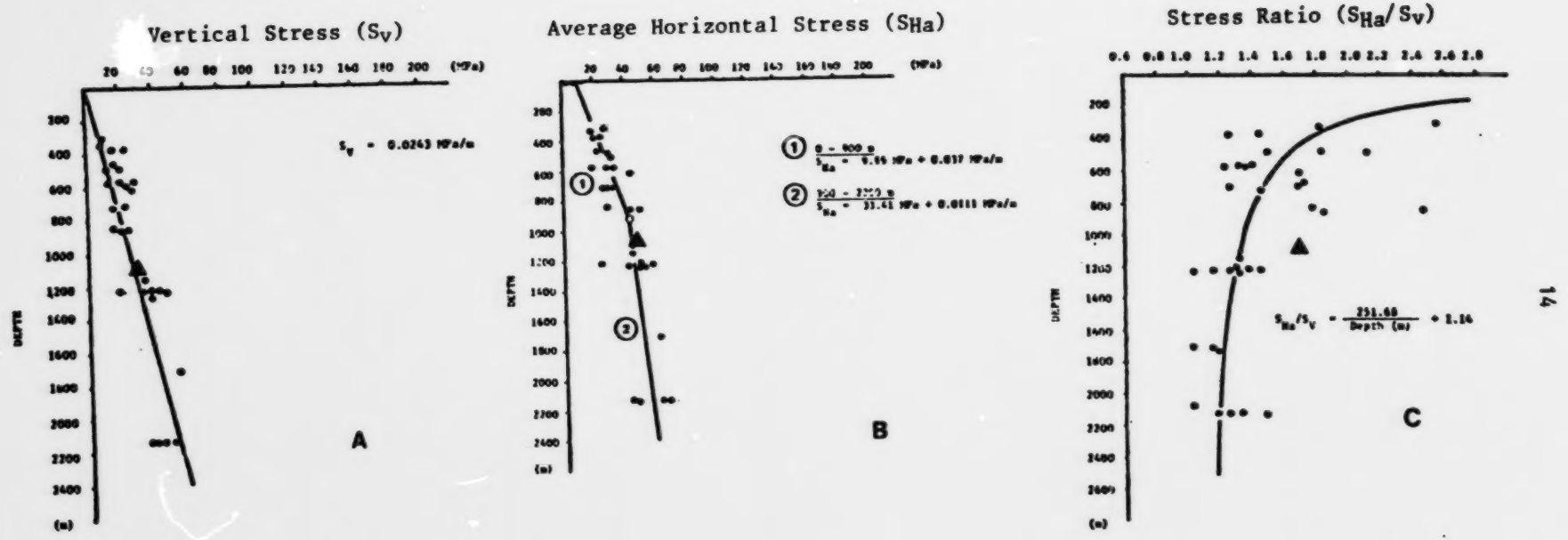


Fig. 6 - Increase of vertical stress (A), average horizontal stress (B) with depth, and variation of stress ratio as a function of depth (C) in the Canadian Shield, after Herget (17). Extreme values were excluded for ease of comparison; values at Stanleigh Mine (▲).

at Stanleigh Mine more quantitative information will be necessary to determine the ground stress distributions in the scale of the mine.

Generally, from the occurrence of core discing and observations of flaking in the vertical exploratory drill holes it can be concluded that ground failures, such as spalling or rock bursts, can be expected. A visual observation of drill holes and examination of the cores could provide useful information about ground stress distributions and zones of high stress concentrations in the mining developments.

## CONCLUSIONS

From the completion of the ground stress determinations the following major points can be established:

1. The horizontal stress is higher than the vertical stress, with an average horizontal stress of about 1.7 times the vertical stress. The vertical component of in situ stress is comparable with the gravitational stress due to the overburden.
2. The maximum pre-mining stress lies in a sub-horizontal plane, acting along the strike of the ore zone.
3. Based on stress determinations and the limited data obtained, the most suitable stresses for numerical modelling are:
   Vertical stress = 28.0 MPa or 0.0263 $MN/m^3$ x depth (m) in MPa
   E-W horizontal stress parallel to strike = 57.0 MPa or 2.0 x vertical stress
   N-S horizontal stress perpendicular to strike = 40.0 MPa or 1.4 x vertical stress.
4. In regard to the non-homogeneous stress field and changes in the material properties some distortions in the stress values obtained can be expected.
5. Ground stress distributions, geologic evidence and rock properties suggest

that higher ground stresses will be encountered in future developments, as the mining progresses.

## ACKNOWLEDGEMENTS

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